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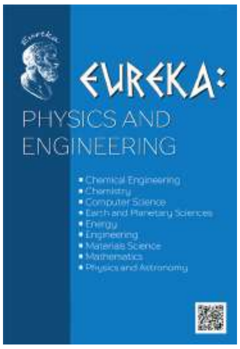

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ANALYSIS OF THE THERMAL PERFORMANCE OF THE LINING AND THE REASONS FOR ITS DESTRUCTION IN PETROLEUM COKE CALCINATION FURNACES

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Abstract

This article discusses the thermal technological processes occurring in petroleum coke calcination furnaces, as well as issues of causes of destruction of the refractory material of the calcination furnace lining. The survey showed that the main factors influencing the duration of the work campaign of the lining are the temperature stresses that arise in the lining during sudden temperature changes during heating or cooling, as well as the chemical effect of the process material on the lining.

It was revealed that in the inlet zone, where the drying of technological raw materials is carried out, the wear of the lining occurs evenly, and there is no significant damage. On thermal imaging images, this zone is displayed as uniform temperature fields on the outer surface of the furnace. In the calcination zone, the lining is characterized by the presence of main cracks that run along the seams. These cracks indicate the occurrence of significant thermal stresses when the furnace is heated. Work was done to determine the dependence of tensile strength on temperature, in the temperature range from 20 °C to 650 °C. Analysis of the results of determining the tensile strength showed a general tendency for it to increase with increasing temperature. This is explained by changes in the structure of the refractory material with increasing temperature and load. Taking into account the obtained dependence of the tensile strength on temperature allows one to adjust the heating schedules of the calcination furnace to reduce the temperature stress during the heating process.

Keywords: calcination furnace, refractories, temperature stresses, tensile strength, temperature regime, lining.

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1. Introduction

Thermal technological processes in petroleum coke calcination furnaces are characterized by a great variety and complexity of thermophysical and thermochemical processes occurring with the participation of various types of fuel and raw materials in changing states of aggregation. This places high demands on all structural components, including the lining.

The lining of furnaces physically wears out most quickly, and its cost, as a rule, determines the duration of the overhaul campaign. Therefore, increasing the durability and reliability of the lining ensures an extension of the furnace's overhaul operating period.

In addition to the duration of the furnace operating campaign, the destruction of refractory materials affects the technological processes in the furnace itself. Due to a decrease in the thickness of the lining as a result of the destruction of refractories, heat losses to the environment increase. This leads to additional fuel and air consumption, and there may also be increased coke burn-off. Coke burn-off occurs due to a violation of the ratio of the lengths of the zones in the furnace and the combustion of calcined coke in the cooling zone of the material instead of the released volatile substances [1].

Consequently, the destruction of the lining refractories not only determines the time for major repairs of the furnace, but also affects fuel consumption and the quality of the resulting technological product.

In the paper [2], the authors note the relevance of thermal effects on the mechanical destruction of the lining when heated in a rotary kiln. At the same time, most research in this area is focused on the study of stationary operation conditions, despite the relevance of thermal effects on the mechanical stress state during heating process.

The relevance of the lining durability from the standpoint of the overall reliability of the operation of high-temperature units is noted in the articles [3–5]. The authors of these articles show that in many cases unscheduled furnace shutdowns are associated with damage to the lining. From the data presented by the authors, it follows that a significant part of the accidents of lined equipment occurs due to underestimation of the influence of non-stationary thermal processes on the strength characteristics of the refractory materials used.

It is important to analyze the reasons that reduce the lining life of high-temperature units. Among the main factors influencing the reliability of the lining, it is worth noting the following. Firstly, these are temperature stresses that arise in the lining during sudden temperature changes during heating or cooling. The cause of temperature stresses exceeding the tensile strength of the refractory materials used may be:

– irrational launch schedules;

– use of heating schedules developed for one refractory material when heating another material (for example, when replacing it);

– spillage of liquid fuel (fuel oil) on the lining due to unstable burner operation;

– malfunctions of measuring instruments and automation.

A number of works note that destruction due to the occurrence of thermal stresses of high-temperature units is the most common cause of destruction of linings [6, 7].

It is also worth noting the research results of the authors of the paper [8], which show that neither tensile nor compressive stresses of the brick lining had a destructive effect in a stationary mode. During the heating process, both compressive and tensile stresses exceeded permissible limits. Compressive forces during cooling of the lining according to the available schedule were classified as safe, and tensile stresses exceeded the permissible ones.

Another factor affecting the reliability of the lining is the chemical effect of the process material on the lining.

Meanwhile, in some works it is noted that the aggressive influence of the technological material on the lining does not have a significant effect; nevertheless, the impregnation of the refractory material contributes to the formation of thermomechanical cracks. Thus, the authors of the paper [9] show that there is no significant thermochemical reaction between the refractory material and the process material. In fact, due to capillary action the melt penetrates into open pores to a depth of up to 5 mm. Beneath this infiltration zone, serious cracks are systematically seen in all types of bricks.

In a number of cases, a significant increase in the thermal conductivity of the layer reacting with the working medium was detected. At the same time, the impregnated part of the refractory is denser and stronger and has a higher thermal conductivity factor than the rest of the refractory. This is especially true when the slag penetrates into the refractory in the slag-line area [10].

The next factor is mechanical abrasion and the impact of the process material on the lining.

From the practical experience of operating the linings of the petroleum coke calcination units, it follows that the main causes of lining wear are related to mechanical and thermal, not chemical factors [11]. Lining wear also occurs as a result of dynamic loading, especially at the cold end of the furnace, where moisture from continuously charged raw coke and frequent temperature fluctuations are observed. In the coke loading area, wear of the lining increases due to the impact and abrasive effects of fragments (up to 75 mm) of the loaded coke. But abrasive wear of the lining is a significant factor in only a small local area of the furnace.

There are a number of other factors that affect the durability of the linings of high-temperature units: the contact time of the technological material and the lining, the presence of a thermal insulation layer, etc. But these factors are relevant only for a part of high-temperature units and their impact is not decisive.

In this regard, it seems appropriate to present in this paper the results of the survey and analysis of the resistance of the lining on the basis of studies of the wear mechanism of the refractory materials used under the influence of a high-temperature environment in real operating conditions of the installation.

2. Materials and Methods

2. 1. Installation inspection

The rotary kiln of a petroleum coke calcination plant was chosen as the object of study.

The calcination furnace consists of a metal body lined with refractory material inside. Concrete blocks with metal «tendrils» at the base are used as a refractory material, which are attached to the furnace body by welding in a row along the entire length of the furnace. The distance between the rows of blocks is filled with special heat-resistant concrete.

The diameter of the furnace is uneven along the entire length, on the material loading side at a distance of 7.5 linear meters, the diameter is 3.75 m, along the remaining length of the furnace 3.47 m. This design solution was made to reduce the speed of exhaust gases and reduce dust removal from the furnace.

The technical characteristics of the furnace are given in **Table 1**:

Table 1
Technical characteristics of the furnace

Diameter, m	3.750–3.470
Length, m	65
Angle of inclination, percentage of length, degree	4
Furnace speed on the main drive, rpm	1.5
Capacity for calcined petroleum coke, t/hour	15.26
Capacity for green petroleum coke, t/hour	20
Coke calcination temperature, °C	1250–1350

Petroleum coke calcination is the process of heating crude petroleum coke to a temperature of 1250–1350 °C. Coke calcination is carried out in a rotary kiln lined with mullite-silica refractory materials (Al_2O_3 = 58 %, SiO_2 = 34 %). The lining is designed to protect the metal body of the furnace from exposure to high temperatures and reduce heat losses to the environment.

Due to the physical and chemical processes occurring with the raw material, there is an improvement in the consumer properties of coke.

After evaporation of moisture and removal of volatile components, the coke is heated to 1350 °C. At the same time, its molecular structure takes on a more organized form with a clear crystal lattice. The main purpose of the calcination process is to improve the physical and chemical properties of the coke, such as electrical conductivity, true density, oxidizability and reactivity.

During transportation, the coke is exposed to high temperatures. The heat required for heating and calcining the coke is provided by the combustion of the fuel, as well as by the volatiles contained in the crude petroleum coke and coke dust. Temperature control in the calcination unit is carried out by means of thermocouples installed at the loading end of the furnace, at the unloading end of the furnace, in the calcination zone, as well as by an infrared pyrometer installed at the unloading end of the calcination unit.

The boundaries and length of the zones in the furnace depend on the fractional composition of the raw materials, moisture content and volatile substances, and may also vary depending on the discharge and volume of the supplied air, the amount of fuel and the speed of rotation of the calcining furnace and the amount of material fed into the furnace.

The quality of the finished product depends on the length of the calcination zone, the temperature in the furnace and the residence time of the material in it. The productivity of the furnace is determined by the ratio of the parameters of the rotation speed of the furnace, the volume of feedstock and temperature, which together make it possible to obtain the calcined coke that meets the requirements of a true density of 2.03–2.09 g/cm^3.

The service life of petroleum coke calcination furnaces is largely determined by the service life of the lining. During operation of the furnace, the thickness of this protective layer constantly decreases, which is a consequence of several influences. Firstly, refractories are exposed to the corrosive factor of an aggressive (as a rule) environment, which the refractories hold in a given volume. Secondly, the destruction of the lining occurs due to the «chipping» of pieces of refractories. The cause of chipping is the formation of microcracks in the material, which later turn into more noticeable damage. The physical and physicochemical phenomena occurring in the masonry and affecting it are complex, interconnected and interdependent. This makes it difficult to interpret full-scale experiments, their theoretical description and, consequently, improve the output parameters of processes and their controllability [12].

According to the data [12], an analysis of refractory wear and failures in a rotary kiln alone shows that about 35 % of the problems are related to thermochemical causes, 28 % – to thermomechanical causes, 19 % – to thermal overload, 3 % – to redox reactions and another 15 % – to reasons other than those mentioned here.

When analyzing the state of the lining of a petroleum coke calcination furnace, it is necessary to conditionally divide the operating period of the equipment into two components, since the nature of the destruction of the lining largely depends on these operating parameters. It is the operation in sharply unstableoperating environment, i. e. all start-up operations and the main cycle, when the furnace operates with relatively small fluctuations in the temperature environment.

Drying and heating of the lining is an integral part of the commissioning process of the calcination furnace. During the process of drying and heating, as the temperature rises, lining materials attain the basic refractory properties. These properties of the lining largely depend on the following factors: installation quality, characteristics of refractory materials, lining thickness, adherence to the drying and heating schedule, as well as further operation (possible overheating, temperature changes, adhesion of the raw material, thermal changes, abrasive and mechanical effects).

Drying and heating of the furnace lining is carried out according to a schedule developed, as a rule, by the enterprise itself, and during this period of lining heating, the rise in temperature should not allow the temperature rise rate to be higher than 5 °C/hour. It should be noted here that this speed limit is chosen from the experience of operating the equipment.

The furnace shutdown schedule is selected according to the recommendations of the refractory materials manufacturer. It is not at all related to the thermal conditions of the furnace at the time of shutdown, which can be either planned or emergency. In this case, the cooling rate of the furnace will certainly be accompanied by significant temperature changes.

The furnace inspection was carried out in two stages. At the first stage an analysis of the thermal operation of the calcination furnace was carried out using thermal imaging studies. For thermal imaging analysis, a Fluke Ti110 thermal imager was used. The second stage was a visual inspection of the inner surface of the furnace lining in order to identify damage.

The existing destruction of the lining is determined mainly by non-stationary thermal processes. As a result of these processes, significant temperature stresses arise that exceed the strength characteristics of the refractory materials used. In this connection, there is a need for a more detailed study of the influence of strength characteristics on the durability of the lining depending on the temperature of the working environment. Since with increasing temperature in some types of refractories, a transition from brittle deformations to the plastic region is possible, which can change the range of changes in the tensile strength of the materials used [13].

2. 2. Determination of the dependence of the tensile strength of a refractory on temperature

To determine the dependence of the tensile strength of mullite-silica refractory brand SEVEN CAST 58 NM on temperature a special experimental stand was used [14].

According to the passport data of the manufacturer «Seven REFRACTORIES», the refractory has the following characteristics: cold crushing strength: 60 MPa; density: 2.46 g/cm^3; temperature coefficient of thermal expansion 0.3 %.

The cold crushing strength (CCS) values given in material manufacturers' data sheets do not always correspond to actual values for the materials used. Room temperature measurements cannot be used directly to predict how a material will behave in service [15, 16].

It is of interest how these characteristics change during the operation of the furnace lining. For this purpose, samples of refractories that had been used inside the furnace were subjected to research. Bricks from the calcination zone after the kiln was taken out for repairs were taken as samples for the study. Determination of the tensile strength of samples of mullite-silica refractory materials was carried out in the range of operating temperatures of the lining: from 100 to 700 °C.

Samples for research were prepared according to the standard [17] in the form of a cube and had the following dimensions – the length of the side of the sample ranged from 30 to 50 mm. When placing the samples in the stand, they were subjected to simultaneous heating and compression.

When determining the tensile strength of refractories, the technique was used [17]. The samples were heated in an oven to the test temperature. They were then subjected to unilateral loading until failure. The maximum pressure recorded was the compressive strength.

3. Results and discussion

3. 1. Results of the analysis of the thermal performance of the furnace

In all zones, the temperature field on the surface of the furnace has characteristic features, somewhere relatively uniform (inlet zone, where technological raw materials are dried), which indicates uniform wear of the lining and the absence of significant damage. This entrance zone is displayed in thermal imaging images as uniform temperature fields on the outer surface of the furnace (**Fig. 1**).

a *b* *c*

Fig. 1. Thermal fields of the surface of the coke calcination furnace: *a* – thermal image of the outer surface of the calcination furnace; *b* – area of the surface of the calcination furnace; *c* – temperature scale of the thermal imaging image

There are zones with elevated temperature (15–20 °C above the average temperature), which are fixed in the area of the air supply tuyeres (**Fig. 2**).

Further examination of the inner surface of the calcination unit lining showed that in areas with elevated temperatures there are chips of refractory lining under the tuyere (**Fig. 3**).

The surface of the lining in the calcination zone is characterized by the presence of main cracks running along the seams. These cracks indicate the occurrence of significant thermal stresses when the furnace is heated (**Fig. 4**).

a *b* *c*

Fig. 2. Zones of elevated temperatures in the tuyere area:
a – thermal image of the outer surface of the calcination furnace; *b* – area of the surface of the calcination furnace; *c* – temperature scale of the thermal imaging image

Fig. 3. Chips of refractories under the tuyere

Fig. 4. The nature of lining destruction in the calcination zone

The average impregnation thickness of refractories is 20–30 mm. The structure of the impregnated part is dense and strong (**Fig. 5**):

Fig. 5. Fragment of a refractory brick

The results of examining the condition of the lining show that the refractories of the lining contain chips and cracks, the formation of which causes the destruction of the lining and the removal of the furnace for repair. From photographs of the external surface of the furnace taken with a thermal imager, it is possible to assess the condition of the internal surface of the lining.

3. 2. Results of determining the tensile strength of mullite-silica refractory materials

The results of the studies are shown in **Fig. 6**:

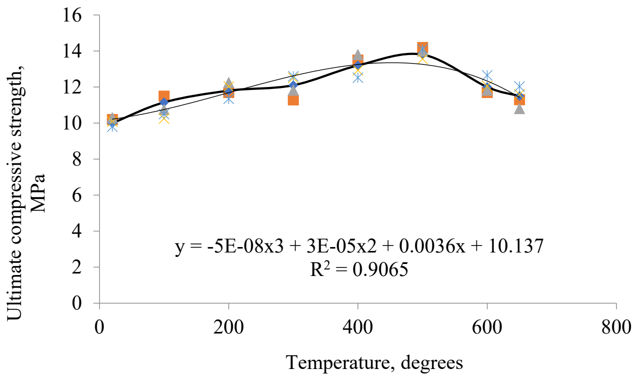

Fig. 6. Dependence of refractory tensile strength on temperature

This study shows the results of five experiments to determine the tensile strength. The graph shows the average compressive strength values. The multi-colored marks on this graph correspond to each individual of the 4 experiments at the corresponding temperature value. The average value of the results of the experiments is connected by the indicated line.

The resulting graph shows that the value of the tensile strength in the entire temperature range under study (from 20 °C to 650 °C) is higher than under initial conditions, that is, at 20 °C. It follows from this that the tensile strength with increasing temperature is higher than under normal conditions.

The curve of the dependence of the ultimate strength on temperature has the following characteristic features: starting from a temperature of about 40 °C, the ultimate strength of the refractory increases, reaching a value of 13.8 MPa (at a temperature of about 500 °C). Then the value of the tensile strength begins to decrease sharply, reaching 11.2 MPa (at 600 °C).

The chipping of the refractories of the lining under the tuyere (**Fig. 3**) is explained by the fact that in the area of the tuyeres the lining is not made of piece refractories, which during operation are sintered into a single monolith, but in a poured form. The poured lining has lower strength characteristics and, with a decrease in its thickness, there is a greater impact on the refractories bordering this zone, which causes their destruction.

Numerous chips at the joints of refractories are caused by clamping of bricks, which is associated with a violation of the temperature regime for calcining coke. The nature of the chips indicates the occurrence of significant tensile forces in the joining joints of the masonry [18].

The destruction of individual lining elements in the hot furnace head shows the result of the influence of several destruction mechanisms. Firstly, the presence of many small cracks is caused by temperature gradients as a consequence of violations of temperature conditions. Secondly, the presence of melted areas leads to peeling of the outer surface of the lining due to different thermophysical properties of the main refractory and the impregnated layer. Thirdly, abrasive wear is observed, since destruction is caused by the abrasive action of the rolling technological product.

Analysis of the results obtained for determining the tensile strength showed a general tendency for it to increase with increasing temperature. This is explained by changes in the structure of the refractory with increasing temperature and load.

Refractories at room temperature are characterized by brittle fracture. Within the limits of elastic deformation, Hooke's law is applied to them. Their strength increases as the temperature increases due to changes occurring in the bond. At temperature increase, the binder (Al_2O_3) transforms into a plastic state and the deformation mechanisms change from elastic to viscoplastic, which is accompanied by an increase in the tensile strength up to a temperature of 500 °C. Further heating reduces the ultimate compressive strength, which is due to an increase in the distances between atoms, the weakening of interatomic bonds and the formation of a liquid phase. The formation of a liquid phase along the boundaries of the crystals and between the grains is the main factor in reducing the strength of the industrial group of refractories [19].

Fig. 7 shows the section of the refractory after its use in the calcination unit.

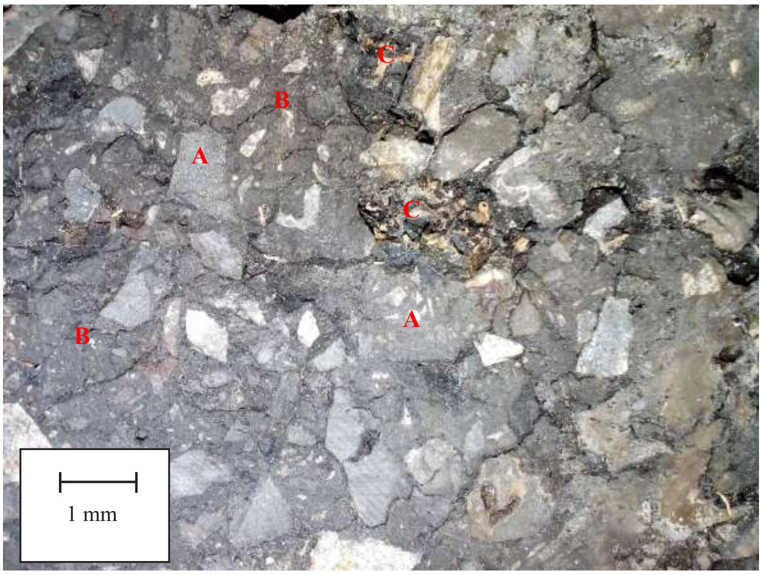

Fig. 7. Incision of a mullite-silica refractory after its use in the calcination unit *A* – SiO_2 grains; *B* – Al_2O_3 binder; *C* – vitreous phase

Silicon oxide grains are represented by large particles, up to 7 mm in size. The intergranular space of aluminium oxide gives significant strength to refractories. In the intergranular space, a glassy phase can also be observed, the formation of which can be explained by the presence of impurities TiO_2, Fe_2O_3, CaO and MgO in the feedstock for the production of refractories [20]. The formation of a vitreous grain-boundary phase reduces the strength of the refractory material and the maximum temperature of use.

Increasing the strength of refractories with increasing temperature shows that under certain conditions for heating the furnace, a more accelerated rate of maintaining the temperature graph can be used. It should be taken into account that the value of the compressive strength in the temperature range up to 700 °C increases up to 38 %. In accordance with this, the increased strength of the refractory materials used allows the furnace heating process to be carried out at higher speeds. This is an additional reserve for increasing the rate of heating of the lining during startup operations, reducing the time and energy resources for heating the unit as a whole.

Analysis of the data obtained shows that after just a year of operation, the strength characteristics of the refractory decrease by almost a third, from 60 MPa to 40 MPa. The nature of the destruction revealed during the inspection of the furnace indicates the presence of significant changes in the integrity of the lining. With further operation of the unit, this can lead to destruction of the lining, since the tensile strength of the refractory materials under study begins to drop sharply.

Consequently, in order to increase the operational period of calcination furnaces, it is necessary to take into account the characteristic features of the behavior of refractories at elevated temperatures when developing start-up and stationary temperature schedules.

The results obtained allow their use only for high-temperature units whose lining contains the same material (Al_2O_3 = 58 %, SiO_2 = 34 %). However, using the dependence of the tensile strength of various refractory materials on temperature makes it possible to adjust the heating rates of any high-temperature units containing the material under study in the lining.

Obtaining the specified dependence of the tensile strength on temperature is possible for any refractory materials in accordance with the methods [17].

4. Conclusions

Analysis of the condition of the lining of the petroleum coke calcination furnace showed that the nature of the damage is a consequence of the discrepancy between the strength characteristics of the refractories used and the thermal conditions of startup and stationary operating modes.

Studies of samples of refractory materials taken from the calcination zone showed an increase in the tensile strength of mullite-silica refractories as a function of temperature by a significant amount. The resulting dependence is nonlinear in the range up to 700 °C.

The study was carried out in the temperature range of 20–650 °C, since according to literature data [21, 22], it is in this range that changes occur in refractory materials that increase their thermomechanical characteristics.

The presence of a significant interval (from 20 °C to 650 °C) in which the tensile strength is higher than under initial conditions makes it possible to intensify the process of heating the furnace at the initial stage, using the specific properties of these refractories. On the other hand, the dependence of the ultimate strength shows that the durability of the refractory lining drops sharply after a year of operation.

Consequently, it is necessary to make adjustments to the thermal schedules for maintaining startup and stationary modes, taking into account the dependence of the strength characteristics of the refractory materials used on the temperature and time of their operation.

Conflicts of interest

The authors declare that there is no conflict of interest in relation to this paper, as well as the published research results, including the financial aspects of conducting the research, obtaining and using its results, as well as any non-financial personal relationships.

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Data availability

Manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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References

[1] Storozhev, Yu. I., Arnautov, A. D., Lapaev, I. I., Evstigneev, V. V. (2011). Increasing the productivity of a rotary kiln for calcining petroleum coke with minimal dust removal. Ecology and Industry of Russia (EKIP), 2, 12–15.

[2] Quintero-Coronel, D. A., Guillin-Estrada, W. D., Echeverri-Roman, J. L., Maury, H., Corredor, L., Ruiz, J. A. et al. (2022). Large- and Particle-Scale energy assessment of reduction roasting of nickel laterite ore for Ferronickel production via the rotary Kiln-Electric furnace process. Thermal Science and Engineering Progress, 32, 101331. https://doi.org/10.1016/j.tsep.2022.101331

[3] Martynova, E. S., Bazhin, V. Y., Kharazov, V. G. (2019). Increasing the level of control and management of arc steel-smelting furnaces. IOP Conference Series: Materials Science and Engineering, 537 (3), 032039. https://doi.org/10.1088/1757-899x/537/3/032039

[4] Qin, J., Qi, J. L. (2012). Analysis on the Refractory Erosion of the Electric Arc Furnace and Study on the Measures of Protecting the Furnace Lining. Advanced Materials Research, 602–604, 2082–2086. https://doi.org/10.4028/www.scientific.net/amr.602-604.2082

[5] Nikiforov, A. S., Prikhod'ko, E. V., Kinzhibekova, A. K., Karmanov, A. E. (2020). Investigation of the Dependence of Refractory Thermal Conductivity on Impregnation with a Corrosive Medium. Refractories and Industrial Ceramics, 60 (5), 463–467. https://doi.org/10.1007/s11148-020-00386-3

[6] Schmitt, N., Berthaud, Y., Hernandez, J. F., Meunier, P., Poirier, J. (2004). Damage of monolithic refractory linings in steel ladles during drying. British Ceramic Transactions, 103 (3), 121–133. https://doi.org/10.1179/096797804225012873

[7] Zabolotskii, A. V. (2013). Modeling of cooling of a steel-teeming ladle. Journal of Engineering Physics and Thermophysics, 86 (1), 205–210. https://doi.org/10.1007/s10891-013-0821-3

[8] Ramanenka, D., Gustafsson, G., Jonsén, P. (2019). Influence of heating and cooling rate on the stress state of the brick lining in a rotary kiln using finite element simulations. Engineering Failure Analysis, 105, 98–109. https://doi.org/10.1016/j.engfailanal.2019.06.031

[9] Villalba Weinberg, A., Varona, C., Chaucherie, X., Goeuriot, D., Poirier, J. (2016). Extending refractory lifetime in rotary kilns for hazardous waste incineration. Ceramics International, 42 (15), 17626–17634. https://doi.org/10.1016/j.ceramint.2016.08.078

[10] Otunniyi, I. O., Theko, Z. V., Mokoena, B. L. E., Maramba, B. (2019). Major determinant of service life in magnesia-graphite slagline refractory lining in secondary steelmaking ladle furnace. IOP Conference Series: Materials Science and Engineering, 655 (1), 012003. https://doi.org/10.1088/1757-899x/655/1/012003

[11] Lapaev, I. I., Sorokin, V. V., Goloskin, S. E., Orlov, A. V. (2019). Lining of the Rotary Kilns for Petroleum Coke Calcination. Refractories and Industrial Ceramics, 60 (1), 1–5. https://doi.org/10.1007/s11148-019-00299-w

[12] Sengupta, P. (2019). Coating and Burnability of Clinker. Refractories for the Cement Industry, 185–192. https://doi.org/10.1007/978-3-030-21340-4_8

[13] Nikiforov, A. S., Prikhod'ko, E. V., Kinzhibekova, A. K., Karmanov, A. E. (2014). Investigation of the Ultimate Strength of Periclase-Carbon Refractory Materials and Analysis of Their High Temperature Strength. Glass and Ceramics, 71 (3-4), 137–139. https://doi.org/10.1007/s10717-014-9636-8

[14] Nikiforov, A. S., Prikhod'ko, E. V., Kinzhibekova, A. K., Karmanov, A. E. (2018). Heat-Engineering Characteristics of Diatomaceous-Earth Materials in a Wide Temperature Range. Glass and Ceramics, 75 (1-2), 60–62. https://doi.org/10.1007/s10717-018-0029-2

[15] Patel, N. (2013). Factors affecting the lifespan of cast refractory linings: a general overview. Journal of the Southern African Institute of Mining and Metallurgy, 113 (8).

[16] Prikhodko, E., Nikiforov, A., Kinzhibekova, A., Paramonov, A., Aripova, N., Karmanov, A. (2023). Analysis of the Effect of Temperature on the Ultimate Strength of Refractory Materials. Energies, 16 (18), 6732. https://doi.org/10.3390/en16186732

[17] BS ISO 22685:2021. Refractory products. Determination of compressive strength at elevated temperature. https://doi.org/10.3403/30408796

[18] Zabolotsky, A. V. (2011). Mathematics modeling of thermal shock in refractory linings. AISTech 2011 Proceedings, 2, 1279–1287.

[19] Kharybina, Y., Pitak, Y. (2017). Studying of the structure of $Al_2O_3 - SiO_2 - CaO - P_2O_5$ system and its significance in the technology of refractories. EUREKA: Physics and Engineering, 4, 11–17. https://doi.org/10.21303/2461-4262.2017.00367

[20] Anggono, J. (2005). Mullite ceramics: its properties structure and synthesis. Jurnal Teknik Mesin, 7 (1), 1–10.

[21] Krivoruchko, O. P., Zhuzhgov, A. V., Bolotov, V. A., Tanashev, Yu. Yu., Molina, I. Yu., Parmon, V. N. (2014). New approach to the novel synthesis of boehmite (γ-AlOOH) by microwave irradiation of gibbsite: Kinetics of solid-phase reactions and dielectric properties of the reactants. Catalysis in Industry, 6 (2), 79–87. https://doi.org/10.1134/s2070050414020056

[22] Yu, K., Yu, J., Lu, Z., Chen, Q. (2015). Determination of the softening curve and fracture toughness of high-strength concrete exposed to high temperature. Engineering Fracture Mechanics, 149, 156–169. https://doi.org/10.1016/j.engfracmech.2015.10.023

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